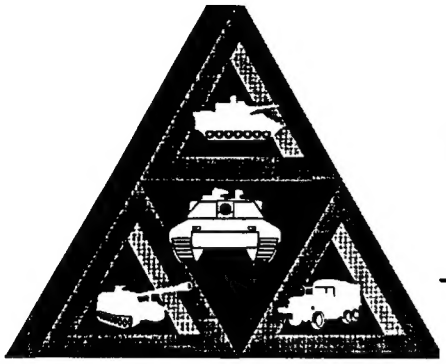
TARDEC



Technical Report

No. 13618

Engineering Evaluation of the MEMCOR Small ROWPU

February 1995

By Chuong Anh Luu
Bob Shalewitz
USA Tank Automotive Command
Mobility Technology Center Belvoir

U.S. Army Tank-Automotive Command
Research, Development and Engineering Center
Warren, Michigan 48397-5000

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1995	Final

4. TITLE AND SUBTITLE
Engineering Evaluation of the MEMCOR Small ROWPU (U)

5. FUNDING NUMBERS

6. AUTHOR(S)
Chuong Luu and Bob Shalewitz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Tank-Automotive RD&E Center
Mobility Technology Center - Belvoir
ATTN: AMSTA-RBWE
10105 Gridley Rd, Ste 128
Fort Belvoir, Virginia 22060-5606

8. PERFORMING ORGANIZATION REPORT NUMBER
TARDEC-TR-13618

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution unlimited; approved for public release.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* The Department of the Air Force, Strategic Air Command (SAC) at Offutt AFB, Nebraska, requested that the MTC-B assist in conducting the inspection and acceptance testing of a Small ROWPU designed and manufactured by MEMCOR.

The evaluation included a seawater and freshwater test to determine whether the small ROWPU met the AF requirements outlined in this report.

The results indicated that while the small ROWPU met water production and quality requirements, there were human factors and safety deficiencies that must be addressed.

14. SUBJECT TERMS

15. NUMBER OF PAGES 48

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

No. 13618

Engineering Evaluation of the MEMCOR Small ROWPU

February 1995

By Chuong Anh Luu
Bob Shalewitz
USA Tank Automotive Command
Mobility Technology Center Belvoir
Water Technology R&D Team

Contents

Page

Section 1 Introduction 1
Background 1
Objectives 1
Description of Equipment 1

Section 2 Operating Procedures 3
Water Production 3
CMF Backwashing 3

Section 3 Engineering Evaluation 5
Seawater Test 5
Freshwater Test 6

Section 4 Discussion and Results 8
Water Production Rate 8
Product Water Quality 8
Permeate Flow versus Temperature 10
Safety and Health Assessment 10
Human Factors Engineering Evaluation 11
Seawater Recovery Rate 12

Section 5 Conclusions 13

Section 6 Recommendations 14

Appendix A Sample Data Sheet A-1

Appendix B Summary of Seawater Test Data B-1

Appendix C Summary of Freshwater Test Data C-1

Appendix D Safety and Health Assessment Report D-1

Appendix E Human Factors Engineering Evaluation Report E-1

Tables

1. Freshwater Test - Water Quality Results 9
2. Seawater Test - Water Quality Data 10

Figure

1. Schematic of the Memtec Small ROWPU 1

Acknowledgements

This report covers an evaluation of the Memtec Small ROWPU conducted by the Water Technology R&D Team of the Mobility Technology Center-Belvoir. STRATCOM Offutt Air Force Base requested and funded the evaluation.

This project was accomplished under the general direction of Thomas H. Bagwell, Chief, Water Technology R&D Team.

The following personnel conducted the evaluation:

Mr. Chuong Anh Luu, Project Engineer
SGT Robert Grable, Water Treatment NCO

Section 1 Introduction

BACKGROUND

The Department of the Air Force, Strategic Air Command (SAC) at Offutt Air Force Base in Nebraska requested that the Mobility Technology Center-Belvoir (MTC), Fort Belvoir, VA assist in conducting the inspection and acceptance testing of a Small Reverse Osmosis Water Purification Unit (Small ROWPU) designed and manufactured by MEMCOR.

The Small ROWPU evaluation occurred during 28 March - 14 April 1994 at MTC's Fort Belvoir facility. The testing was divided into two parts: sea water testing and fresh water testing. After completion of the testing, the system was preserved, packaged and shipped to Offutt Air Force Base, Nebraska for further evaluation by the Air Force.

OBJECTIVES

The objectives of this Engineering Evaluation were to:

1. Determine if the MEMCOR Small ROWPU can produce a minimum of 3763 gallons of potable water when operating on a 25°C water source for a twenty-two hour period.

2. Verify that the Small ROWPU's product water meets Army drinking water standards outlined in Technical Bulletin, Medical Number 577: Sanitary Control and Surveillance of Field Water Supplies (TB MED 577).

3. Determine if the MEMCOR Small ROWPU's reduction in permeate flow rate per degree C (starting from 25°C) is less than 3.5%.

4. Determine if the MEMCOR Small ROWPU minimizes operator risks and safety hazards.

5. Determine if the Small ROWPU meets Human Factors Performance and Engineering Criteria outlined in MIL-STD-1472.

6. Verify that the Small ROWPU has a minimum product water recovery rate of 25% when operated on 25°C seawater.

DESCRIPTION OF EQUIPMENT

The MEMCOR Small ROWPU is a trailer mounted, water purification system capable of producing 171 gallons per hour (GPH) of potable water when operated on a contaminated fresh, brackish or sea water source at 25°C. The Small ROWPU is a self-contained system weighing 6500 pounds and powered by a 20 KW, diesel generator set (included with the unit).

The unit uses a continuous Cross-flow Microfiltration system (CMF) to remove suspended solids from the feed water. The CMF system employs MEMCOR's patented gas backwash cleaning system to flush collected suspended material from the surface of the CMF membranes. This allows for long periods of operation between time consuming chemical cleanings.

The Small ROWPU also contains a reverse osmosis (RO) subsystem to reduce the levels of any dissolved solids and organic contaminants, contained in the feedwater, down to drinking water standards. The unit used during the evaluation was MEMCOR Serial Number 5048. A schematic for the system is included as Figure 1.

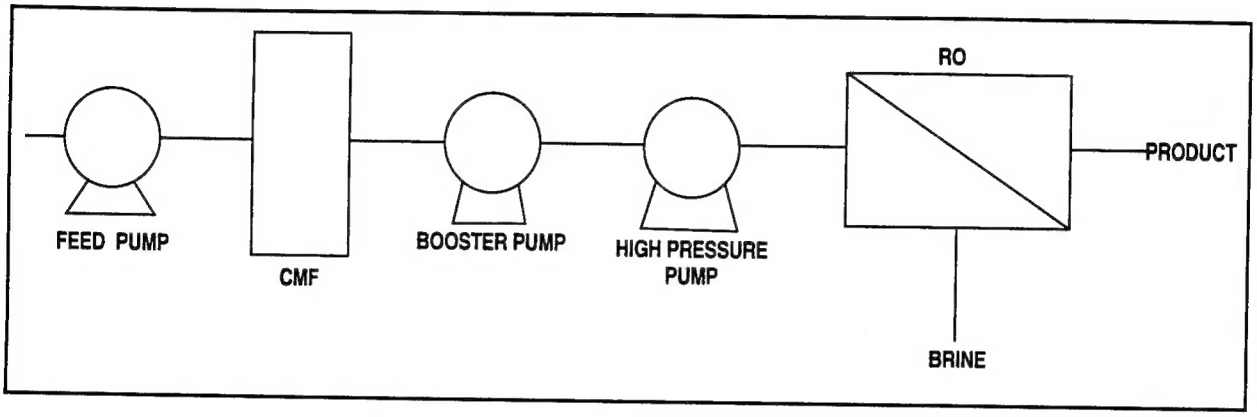


Figure 1. Schematic of the Memtec Small ROWPU

Section 2 Operating Procedures

Throughout the Engineering Evaluation, MEMCOR representatives operated the Small ROWPU in accordance with its Operation and Maintenance (O&M) manual. A programmable microprocessor unit, included in the system, monitored and controlled the operating sequences of the Small ROWPU during water production and backwashing. The microprocessor controlled the solenoid valves, pumps and control panel indicators. Various input signals are used by the microprocessor to indicate the unit's operating status. The following paragraphs describe the unit processes employed during normal water production and CMF backwashing operations.

WATER PRODUCTION

A submersible pump transfers untreated water from the raw water source to the Small ROWPU system. A chemical dosing pump injects sodium thiosulfate into the raw water if the operator determines there is more than 0.05 ppm of residual chlorine in the water. A cleanable 420 micron duplex strainer filters large suspended particles from the raw water prior to its entering the CMF system.

The CMF system consists of three (3) discrete filtration modules each housing a bundle of 0.2 micron hollow fiber membranes. The modules operate in a parallel configuration.

Feed water enters each module at one end and flows along the outside of the fibers where a portion of the water passes through the walls of the fibers. The remainder of the feed stream washes away the particulates trapped on the outside of the fibers. A 75 gallon tank collects the filtrate from the center of the fibers for use as the feedwater to the RO section of the system.

A booster pump transfers the CMF filtrate from the storage tank to the suction of a high pressure pump. The high pressure pump pressurizes the water and pumps it through the RO system. The RO subsystem consists of two pressure vessels, each containing two, 6-inch diameter, spiral-wound, RO elements. The vessels operate in a parallel configuration. The RO elements remove most of the dissolved solids contained in the feedwater.

The product from the RO subsystem consists of a stream of highly concentrated brine and a stream of desalinated filtrate. The ratio of brine to filtrate is typically 2:1 when operated on seawater and 1:1 when operated on freshwater. The brine discharges back into the source water. The filtrate is chlorinated and stored for distribution.

CMF BACKWASHING

The microprocessor controls CMF backwashing. The backwashing can occur at intervals of up to 30 minutes. The patented gas backwash system prevents the build-up of solids on the surface of the fibers. This build-up can reduce the amount of product water obtained per unit area of CMF membrane.

During the backwash cycle, the fibers are expanded by forcing air into them. The solids, on the surface of the fibers, are dislodged by releasing the air and then are flushed out of the modules. The fibers are then rewet (automatically) and placed back into normal service.

Section 3 Engineering Evaluation

The Engineering Evaluation consisted of two (2) tests, a 40-hour seawater test and a 40-hour fresh water test. Each test was performed at the US Army Mobility Tech Center-Belvoir during the following dates:

Seawater Testing: 29 March - 4 April 1994
Fresh Water Testing: 5 - 14 April 1994

SEAWATER TEST

Equipment Operation

The 40-hour Seawater Test occurred at the test pad near Building 325. The unit operated eight (8) hours a day for a period of five days. The test water was synthetic seawater prepared in accordance with ASTM Standard D1141-52. The characteristics of the feedwater were as follows:

Feed water TDS: 37,000±1000 ppm
pH: 7± 0.5

The feed water was contained in a 3000 gallon tank. All product and brine was recycled back into the feed water storage tank. Feed water salinity and pH were monitored hourly and adjusted by the addition of synthetic sea salt, RO product water, hydrochloric acid or sodium hydroxide as required.

The Small ROWPU operated in accordance with its O&M Manual (Doc. No. TM 40W4-600001-000-2) during the test. A CMF backwash interval of every 30 minutes was used for the duration of the test.

Data Collection

During the testing, the operator collected samples of source water, CMF filtrate, RO brine and RO product water and analyzed them for Total Dissolved Solids (TDS), pH and turbidity. The temperature of the source water was also measured hourly. The data was recorded on a test data sheet, and example of which can be found at Appendix A.

The following instrumentation was used during the seawater test:

Conductivity Meter: Myron L Model # 532TI
Turbidimeter: Analyte Model # 156
pH Meter: Orion Model # SA250 with Auto Temperature Adjustment
Thermometer: Mercury Type

The following system information was recorded hourly during the testing:

Total Hours Operated
Cumulative Product Flow
RO Feed Pressure
CMF Inlet Pressure
CMF Outlet Pressure
CMF Differential Pressure
Product Flow Rate
Brine Flow Rate

Gauges mounted on the Small ROWPU provided the above information.

In addition, source, CMF filtrate, RO product and RO brine water samples were taken at the start and completion of the 40-hour test. The samples were sent to Environmental System Services (ESS) for analysis. ESS analyzed the samples for the presence of the following contaminants:

Lead
Iron
Copper

Also, the Human Research and Engineering Directorate (HRED) of Fort Belvoir performed a Human Engineering evaluation on the Small ROWPU. The evaluation occurred during the period of 29 - 30 March. The Small ROWPU was checked for conformance with MIL-STD-1472 and MIL-STD-1474C.

FRESH WATER TEST

The 40-hour Fresh Water Test was conducted at the Belvoir Potomac River Test Site located between buildings T-386 and T-394 on Whitestone Point. The unit operated eight (8) hours a day for a period of five days. The test water was natural Potomac River water. The Characteristics of the feedwater were as follows:

Parameter	Min.	Max.	Avg.
TDS (ppm)	117	170	133
pH	6.8	7.7	7.2
Turbidity (NTU)	5.5	30.0	14.2
Temperature (F)	55.8	66.1	58.7

Since a natural water source was used, the feed water quality tended to vary depending on the time of day, the weather and tidal conditions.

During the first four days of the test, the product and brine water from the Small ROWPU were collected in a 3000 gallon onion tank and discharged back into the river. On the last day of testing, the water was discharged from the onion tank to the local wastewater

treatment facility for disposal. The change in discharge point had no effect on the operation of the Small ROWPU.

The Small ROWPU operated in accordance with its O&M Manual (Doc. No. TM 40W4-600001-000-2) during the test. A CMF backwash interval of every 30 minutes was used during the Fresh Water test.

Data Collection

During the testing, the operator collected samples of source water, CMF filtrate, RO brine and RO product water and analyzed them for Total Dissolved Solids (TDS), pH and turbidity. The temperature of the source water was also measured hourly. The data was recorded on a test data sheet, and example of which can be found at Appendix A.

The instrumentation used during the Seawater Test to measure temperature, turbidity, TDS and pH was also used during the Fresh Water Test.

The following system information was recorded hourly during the testing:

Total Hours Operated
Cumulative Product Flow
RO Feed Pressure
CMF Inlet Pressure
CMF Outlet Pressure
CMF Differential Pressure
Product Flow Rate
Brine Flow Rate

Daily samples of the source, CMF filtrate, RO brine and RO product water were collected and sent to Environmental System Services (ESS) for analysis. The samples were analyzed for the presence of the following contaminants:

Color
Chloride
Sulfate
Cyanide
Arsenic
Magnesium
Fecal Coliforms

Also, MTC-B's Technical Support Team performed a Safety and Health Assessment on the Small ROWPU during the Fresh Water Test. The Technical Support Team evaluated the Small ROWPU and its O&M Manual against the requirements contained in the Air Force SOW included in Contract No. F25606-92-C-0013.

Section 4 Results and Discussion

WATER PRODUCTION RATE

The first objective of the test was to determine if the Small ROWPU can produce a minimum of 3763 gallons per day when operating on a 25°C water source. A day, as defined in the contract, was to be 22 hours of operation.

During the sea water test the Small ROWPU produced an average of 4901 GPD (corrected to 25°C) during the 40 hours of testing. The average operating pressure during this period was 735 psi. The data collected during the Seawater test is in Appendix B of this report.

During the fresh water testing the Small ROWPU produced an average of 5489.7 GPD during the test period. The average operating pressure was 206 psi. The data collected during the Fresh Water test is in Appendix C of this report.

The testing verified that the Small ROWPU can easily meet the water production requirement on fresh water even when operating at low pressure. On seawater, the unit met its production goal while operating at a slightly lower pressure than the 1000 psi maximum. This will allow the unit to meet its required production rate even as the RO elements foul and product water flux declines.

PRODUCT WATER QUALITY

Environmental Sciences and Services (ESS) provide analytical support for the chemical analysis of the water samples collected during the Small ROWPU evaluation.

Water samples were collected at the start and finish of the seawater test and at four different times during the fresh water evaluation. All samples were grab samples. The samples, preserved according to ESS instructions, were refrigerated until transport from Fort Belvoir to the ESS laboratory.

ESS analyzed the freshwater samples for the presence of contaminants regulated under TB MED 577. The results of the analysis are in Table 1.

In all cases, the product water met the TB MED 577 standards, however, except for turbidity and coliforms, the feed water also met the criteria.

The analysis of salt rejection data gathered during the sea water test indicated that, when operating on a seawater source, the Small ROWPU produced a water with less than 1000 ppm of TDS, thereby meeting the TB MED 577 standard for TDS.

Table 1. Freshwater Test - Water Quality Results

FEEDWATER							
Sample Date	Color	CL (mg/l)	SO4 (mg/l)	CN (mg/l)	AS (mg/l)	MG (mg/l)	COLIFORMS (MPN/100ML)
5 Apr	40	9.1	23	<0.02	0.002	3.9	350
6 Apr	30	10.6	22	<0.02	0.001	4	22
7 Apr	50	10.1	<10	<0.02	0.003	3.2	>1600
14 Apr	40	12.3	30.5	<0.02	<0.001	4.9	240
CMF FILTRATE							
Sample Date	Color	CL (mg/l)	SO4 (mg/l)	CN (mg/l)	AS (mg/l)	MG (mg/l)	COLIFORMS (MPN/100ML)
5 Apr	10	9.1	21	<0.02	0.001	3.9	<2
6 Apr	10	8.5	20	<0.02	0.001	4	<2
7 Apr	5	9.6	15	<0.02	0.002	3.7	<2
14 Apr	10	7.2	24.7	<0.02	0.002	5.3	<2
PRODUCT WATER							
Sample Date	Color	CL (mg/l)	SO4 (mg/l)	CN (mg/l)	AS (mg/l)	MG (mg/l)	COLIFORMS (MPN/100ML)
5 Apr	5	1.3	<10	<0.02	0.001	0.11	<2
6 Apr	5	3.4	<10	<0.02	0.002	0.12	<2
7 Apr	5	3.9	<10	<0.02	0.002	<0.1	<2
14 Apr	5	0.9	<10	<0.02	0.001	<0.1	<2

Although the test results indicated there was some removal of the TB MED 577 regulated contaminants, due to the small amounts of the contaminants contained in the feed water, the results are inconclusive. However, both the 600 and 3000 GPH ROWPUs use RO to remove these contaminates and both have been shown to meet TB MED 577 requirements. Since the Small ROWPU also uses RO, it is likely that it also will meet the requirements of TB MED 577.

During the Seawater testing, water samples were taken to determine if any metals from the Small ROWPU piping system were leaching into the water. The results of the ESS analyses are in Table 2. From the data collected, it does not appear that such leaching is occurring in the Small ROWPU.

Table 2. Saltwater Test - Water Quality Data

	FEED			CMF FILTRATE			RO REJECT			PRODUCT		
Sample Date	PB (mg/l)	CU (mg/l)	FE (mg/l)	PB (mg/l)	CU (mg/l)	FE (mg/l)	PB (mg/l)	CU (mg/l)	FE (mg/l)	PB (mg/l)	CU (mg/l)	FE (mg/l)
29 Mar	<0.005	0.14	0.41	<0.005	0.12	0.42	<0.005	0.15	0.5	<0.005	<0.05	<0.05
4 Apr	0.008	0.13	0.49	<0.005	0.13	0.39	<0.005	0.17	0.54	<0.005	<0.05	<0.05

PERMEATE FLOW VERSUS TEMPERATURE

Another test objective was to determine the effect of feed water temperature on the Small ROWPU's production rate. A means of controlling the feed water temperature was not available during the evaluation, however, there was enough natural variation in raw water temperature, during both the fresh and sea water testing, to perform the analysis.

The feedwater temperatures varied from 11.1°C to 24.4°C during the seawater test and from 13.2°C to 18.9°C during the fresh water test.

To meet the criteria, the decline in product water flow must not exceed 3.5% per degree °C of temperature drop. The results of the analysis showed that the Small ROWPU always met this criteria during the test. The average reduction in flow per °C was 2.7% and 2.6% during the seawater and freshwater test respectively. The maximum reduction recorded was 3.45% and occurred during the 40th hour of the fresh water test. The supporting test data are in Appendices B and C of this report.

SAFETY AND HEALTH ASSESSMENT

MTC's Technical Support Team performed a safety and health assessment on the Small ROWPU during the period of 4-8 APR 94. The assessment examined the areas of maintenance safety, acoustical noise, hazardous materials, electrical safety, personnel safety, mechanical safety and O&M Manual adequacy.

The Technical Support Team found numerous safety and health hazards or shortcomings. The most serious were as follows:

- No capability to prevent system start-up during maintenance
- The procedures for depressurizing the system are unclear
- Exterior and internal noise levels are high
- Material Safety Data Sheet (MSDS) for sodium thiosulfate is not in the manual
- Chemical feed pump connections are identical and could lead to cross connection
- Protective clothing for chemical usage not provided

- Alternator control box not rated for outdoor service
- All motors do not have NEMA-4 protection
- Circuit breakers not labeled
- Outside exhaust flue not insulated
- Diesel fuel must be lifted and poured into a filler 57 inches above ground. May be difficult for shorter personnel and any spillage may be a fire hazard.
- Unit has several head strike hazards.
- No trailer floor drains; Standing water is possible electrical hazard.
- No fire extinguisher provided.
- No fuel gauge to aid operators during filling.
- Hydraulic leveling jack has only 2 ton capacity, trailer weighs 3 tons.
- Unit has several electrical grounding problems.

The results of the evaluation indicate that there are several safety and health hazards and as a result, the Small ROWPU does not meet the criteria for minimizing safety and health risks for personnel. A copy of the complete Health and Safety Report is in Appendix D of this report.

HUMAN FACTORS ENGINEERING EVALUATION

The Human Research and Engineering Directorate (HRED) performed a brief Human Engineering evaluation on the Small ROWPU on 30 March 1994. HRED evaluated the system's Human Engineering design and its acoustical noise.

The results of the evaluation indicated then the Small ROWPU did not conform with MIL-STD-1472 in several ways. The unit also exceeded the interior and exterior noise levels required by MIL-STD-1474C.

The following are some of the major human engineering problems associated with the Small ROWPU. A complete version of the final report submitted by the HRED is in Appendix E of this report.

Major Human Engineering Problems

- Fuel fill port is too high. May lead to spillage and a fire hazard.
- Engine battery difficult to access.
- Muffler and exhaust stack are not insulated and are thermal contact hazards.
- Electrical equipment is not protected from water.
- Generator gauges are difficult to see and read.

For these reasons, the human engineering design of the Small ROWPU is unacceptable. A proper redesign can correct most of these deficiencies.

SEAWATER RECOVERY RATE

The Small ROWPU is required to recover 25% of its feedwater as potable water operated on a 25°C seawater source. This requirement was evaluated during the 40 hour seawater test previously described.

Recovery Rate is defined as follows:

$$\% \text{ Recovery Rate} = \frac{\text{Product Water Flow Rate (corrected to 25°C) x 100}}{\text{Feed Water Flow Rate - Production Flow Rate (@25°C)}}$$

The data collected during the testing is in Appendix B of this report.

During the test, the calculated average recovery rate was 31.2% with a minimum of 28% and a maximum of 36%. Therefore, the Small ROWPU exceeded the requirement of 25%.

Section 5 Conclusions

As a result of the engineering evaluation conducted on the MEMCOR Small ROWPU unit, the following conclusions were drawn:

1. The Small ROWPU, in its present configuration, can produce the required 3763 GPD when operating on a 25°C water source.

2. It is highly likely that the Small ROWPU can produce a product water meeting TB MED 577 when operated on a fresh, brackish or sea water source.

3. The reduction in the Small ROWPU's permeate flow rate per °C is less than the allowable 3.5%.

4. The Small ROWPU meets the required minimum recovery rate of 25% when operating on a 25°C seawater source.

5. The Small ROWPU did not meet Human Factors Performance and Engineering Criteria outlined in MIL-STD-1472.

6. The Small ROWPU exceeded the internal and external noise level requirements of MIL-STD-1474C.

7. The Small ROWPU has several operator health and safety hazards or shortcomings and as such does not meet military health and safety requirements.

Section 6 Recommendations

1. Redesign the system to meet the health, safety and human engineering shortcomings contained in the Safety and Health and Human Engineering Assessment Reports (Appendices D and E).

2. Examine noise reduction techniques to reduce Small ROWPU internal and external noise levels to MIL-STD-1474C standards.

3. Update system manuals to reflect the suggestions contained in the Health and Safety and Human Engineering Assessment Reports (Appendices D and E).

4. Retest the Small ROWPU on a feed water containing enough TD MED 577 regulated compounds to verify that the Small ROWPU can effectively remove these substances.

Appendix A Small ROWPU Engineering Evaluation Data Sheet

TIME _____ DATE _____

UNIT HOURS _____

TOTAL FLOW _____

FILTRATE FLOW _____

FILTRATE PRESSURE _____

REJECT PRESSURE _____

REJECT FLOW _____

RO PRESSURE _____

PRODUCT FLOW _____

WATER QUALITY SAMPLES

PRODUCT		**BY-PASS (CMF)**	
TDS	_____	TDS	_____
pH	_____	PH	_____
TURB	_____	TURB	_____
RAW		**REJECT**	
TDS	_____	TDS	_____
PH	_____	PH	_____
TURB	_____	TURB	_____
TEMP	_____		

OPERATOR(S): _____

WATER SOURCE: _____

NOTES: _____

_____

_____

_____

Appendix B Summary of Saltwater Test Data

MEMTEC ENGINEERING EVALUATION SALT WATER TEST DATA

DATE	TIME	TIME (HRS)	RO PRESS (psi)	CMF FILTRATE PRESS	CMF FEED PRESS	CMF DELTA PRESS	FEED TEMP (F)	FEED TEMP (F)	% REDUCTION	TEMP CORR FACTOR	PRODUCT FLOW (GPM)	NORMAL PRODUCT FLOW (GPM	PRODUCT FLOW (GPD)	NORMAL PRODUCT FLOW (GPD)	BRINE FLOW (GPM)	RECOVERY RATE %	NORMAL REC RATE %
3/29/94	930	1	762	23.4	29.3	5.9	11.1	52.0	2.5	1.532	3.1	4.7	4092	6268.9	9.1	25	34
	1030	2	764	24.5	30.2	5.7	12.5	54.5	2.5	1.466	3.1	4.5	4092	5998.9	8.1	28	36
	1130	3	753	23.5	29.6	6.1	12.8	55.0	2.5	1.452	3.1	4.5	4092	5941.6	8.1	28	36
	1230	4	755	24.8	30.6	5.8	14.4	58.0	2.6	1.376	3.1	4.3	4092	5638.8	8.1	28	35
	1330	5	754	24.9	30.2	5.3	15.0	59.0	2.6	1.354	3.1	4.2	4092	5540.6	8.1	28	34
	1430	6	728	24.7	29.9	5.2	15.9	60.6	2.6	1.317	3.1	4.1	4092	5389.2	8.1	28	34
	1530	7	712	25.3	30.6	5.8	16.7	62.0	2.7	1.285	3.1	4.0	4092	5256.2	8.1	28	33
	1630	8	719	24.9	30.4	5.5	16.7	62.0	2.7	1.285	3.1	4.0	4092	5256.2	8.1	28	33
3/30/94	815	9	743	24.4	30.1	5.7	14.4	58.0	2.6	1.376	3.1	4.3	4092	5638.8	9.1	25	32
	915	10	725	24.4	30.0	5.6	15.6	60.0	2.6	1.331	3.1	4.1	4092	5446.5	8.1	28	34
	1015	11	727	25.5	30.9	5.4	16.4	61.5	2.7	1.296	3.1	4.0	4092	5303.2	8.1	28	33
	1115	12	722	25.7	30.3	4.6	17.5	63.5	2.7	1.253	3.1	3.9	4092	5127.3	8.1	28	32
	1215	13	718	25.5	30.8	5.3	18.6	65.5	2.7	1.211	3.1	3.8	4092	4955.4	8.1	28	32
	1315	14	708	25.7	30.7	5.0	19.4	67.0	2.7	1.180	3.1	3.7	4092	4828.6	8.1	28	31
	1415	15	718	26.1	31.2	5.1	20.4	68.8	2.8	1.145	3.1	3.5	4092	4685.3	8.1	28	31
	1515	16	708	25.7	30.7	5.0	20.6	69.0	2.8	1.142	3.1	3.5	4092	4673.1	8.1	28	30
	1615	17	710	26.1	31.1	5.0	21.1	70.0	2.8	1.122	3.1	3.5	4092	4591.2	8.0	28	30
	1715	18	723	26.6	31.5	4.9	21.1	70.0	2.8	1.122	3.0	3.4	3960	4443.1	8.0	27	30
	1815	19	699	25.8	30.9	5.1	21.7	71.0	2.8	1.104	3.0	3.3	3960	4371.8	8.0	27	29
3/31/94	830	20	749	25.2	30.6	5.4	17.2	63.0	2.7	1.264	3.1	3.9	4092	5172.3	8.1	28	33
	930	21	740	25.1	30.1	5.0	17.8	64.0	2.9	1.264	3.1	3.9	4092	5172.3	8.1	28	33
	1030	22	721	25.2	30.2	5.0	18.8	65.8	2.7	1.204	3.1	3.7	4092	4926.8	8.1	28	32
	1130	23	728	25.2	30.4	5.2	19.4	67.0	2.7	1.180	3.1	3.7	4092	4828.6	8.0	28	31
	1230	24	745	25.9	30.9	5.0	20.4	68.8	2.8	1.145	3.1	3.5	4092	4685.3	8.1	28	30
	1330	25	737	25.7	30.7	5.0	21.1	70.0	2.8	1.122	3.1	3.5	4092	4591.2	8.1	28	30
	1430	26	742	26.1	30.7	4.6	21.7	71.0	2.8	1.104	3.0	3.3	3960	4371.8	8.0	27	29
	1530	27	737	26.1	30.7	4.6	22.2	72.0	2.9	1.086	3.0	3.3	3960	4300.6	8.1	27	29
	1630	28	738	25.6	30.5	4.9	22.2	72.0	2.9	1.086	3.1	3.4	4092	4443.9	8.0	28	30
	1730	29	748	26.3	31.3	5.0	22.2	72.0	2.9	1.086	3.0	3.3	3960	4300.6	8.0	27	29
	1830	30	738	26.1	31.1	5.0	22.2	72.0	2.9	1.086	3.1	3.4	4092	4443.9	8.1	28	29
4/4/94	830	31	753	24.5	30.1	5.6	16.9	62.5	2.7	1.274	3.1	3.9	4092	5213.2	9.1	25	30
	930	32	750	24.6	30.3	5.7	17.7	63.8	2.7	1.247	3.1	3.9	4092	5102.7	8.1	28	32
	1030	33	746	24.9	30.3	5.4	18.3	65.0	2.7	1.221	3.1	3.8	4092	4996.3	8.1	28	32
	1130	34	749	25.5	31.0	5.5	19.4	67.0	2.7	1.180	3.1	3.7	4092	4828.6	8.1	28	31
	1230	35	744	26.0	31.3	5.3	21.0	69.8	2.8	1.126	3.1	3.5	4092	4607.6	8.1	28	30
	1330	36	738	26.3	31.5	5.2	22.2	72.0	2.9	1.086	3.0	3.3	3960	4300.6	8.0	27	29
	1430	37	731	26.0	31.1	5.1	23.1	73.5	2.9	1.059	3.0	3.2	3960	4193.6	8.0	27	28
	1530	38	740	26.5	31.5	5.0	23.6	74.5	2.9	1.042	3.0	3.1	3960	4126.3	8.0	27	28
	1630	39	735	25.9	30.8	4.9	24.2	75.5	2.9	1.025	3.0	3.1	3960	4059.0	8.0	27	28
	1730	40	742	25.8	31.3	5.5	24.4	76.0	3.0	1.017	3.0	3.1	3960	4027.3	8.0	27	28
AVERAGES			735.0	25.4	30.6	5.2	19.0	66.1	2.7		3.1	3.7	4059.0	4901.3	8.1	27.4	31.2

MEMTEC ENGINEERING EVALUATION SALT WATER TEST DATA

			RAW WATER				PRODUCT WATER				RO REJECT WATER		CMF FILTRATE			
DATE	TIME	ELAPSED TIME (HRS)	TEMP. (F)	pH	TURBIDITY (NTU)	TDS (PPM)	pH	TURBIDITY (NTU)	TDS (PPM)	% REJECTION	pH	TURBIDITY (NTU)	TDS (PPM)	pH	TURBIDITY (NTU)	TDS (PPM)
3/29/94	1000	1	52.0	7.8	4.9	37000	5.8	0.1	235.8	99.36	8.1	1.3	40000	8	0.6	39000
	1100	2	54.5	7.9	4.8	37500	5.8	0.2	231	99.38	8	1.6	40000	8.1	0.5	39500
	1200	3	55.0	7.8	5.0	37000	5.5	0.1	230.6	99.38	8.1	1.2	40000	8	0.7	39000
	1300	4	58.0	7.9	4.6	37000	5.9	0.1	225	99.39	8.1	1.7	40000	8	0.6	39000
	1400	5	59.0	7.9	6.3	38000	5.9	0.1	224	99.41	8	1.4	39500	8.1	0.6	39000
	1500	6	60.6	8.1	4.9	37000	6.0	0.1	243	99.34	7.9	0.3	40000	8.1	0.5	40000
	1600	7	62.0	8.0	4.5	36000	5.8	0.0	243	99.33	8	0.6	40000	8.1	0.4	40000
	1700	8	62.0	7.8	4.6	38000	5.9	0.1	243	99.36	7.9	0.6	40000	8	0.5	40000
3/30/94	815	9	58.0	7.8	5.0	33500	5.7	0.0	237	99.29	8	0.3	41000	8.1	0.1	34000
	915	10	60.0	7.9	5.1	33000	5.8	0.0	243	99.26	8	0.2	41000	8	0.2	34000
	1015	11	61.5	8.0	4.9	34000	6.0	0.1	248	99.27						
	1115	12	63.5	7.8	4.9	34000	5.8	0.1	250	99.26	8	0.4		7.9	0.3	
	1215	13	65.5	7.8	4.8	34500	5.9	0.0	260	99.23	7.9	0.2		8	0.1	
	1315	14	67.0	7.2	5.5	35000	5.7	0.1	265	99.24	8	0.4	42000	7.8	0.3	35000
	1415	15	68.8	7.1	5.1	36000	5.9	0.1	280	99.22	8	0.3	42000	7.8	0.2	35500
	1515	16	69.0	7.8	5.5	35000	6.2	0.0	280	99.20	7.9	0.1	42000	8	0.1	34900
	1615	17	70.0	7.3	5.5	36000	6.1	0.0	280	99.22	8	0.3	42000	7.9	0.1	35000
	1715	18	70.0	7.4	5.1	36000	5.9	0.1	274	99.24	7.9	0.4	42000	8	0.2	36000
	1815	19	71.0	7.6	4.9	36000	5.8	0.1	285	99.21	7.8	0.4	42000	7.9	0.3	36000
3/31/94	830	20	63.0	7.9	4.9	36500	6.2	0.0	251	99.31	8	0.2	43500	7.9	0.1	36000
	930	21	64.0	7.6	5.0	36000	6.1	0.0	248	99.31	7.9	0.3	43000	8	0.1	35800
	1030	22	65.8	7.8	5.1	36000	6.0	0.0	254	99.29	7.9	0.3	44000	8	0.2	36000
	1130	23	67.0	7.9	5.0	36500	6.1	0.0	259	99.29	8	0.4	44000	8.1	0.3	36000
	1230	24	68.8	7.6	5.2	37000	5.9	0.0	274	99.26	8	0.3	44500	7.8	0.2	36500
	1330	25	70.0	7.8	5.0	37000	6.1	0.0	282	99.24	7.9	0.4	44000	7.8	0.3	36500
	1430	26	71.0	7.7	5.2	36000	5.7	0.0	284	99.21	7.9	0.1	43000	8	0.1	36000
	1530	27	72.0	7.6	5.1	36000	5.9	0.0	287	99.20	7.8	0.2	44000	8	0.1	36000
	1630	28	72.0	7.2	5.2	36000	6.0	0.0	283	99.21	8		44000	7.9		36000
	1730	29	72.0	7.5	5.3	36000	5.8	0.0	278	99.23	8	0.2	44000	7.9	0.1	36000
	1830	30	72.0	7.6	5.1	36000	5.9	0.0	278	99.23	7.9	0.2	43000	8	0.1	36000
4/4/94	830	31	62.5	7.7	3.6	36000	5.5	0.0	255	99.29	7.7	0.1	44000	7.9	0.1	36000
	930	32	63.8	7.6	3.9	36000	15.6	0.0	255	99.29	7.9	0.2	44000	7.8	0.1	36000
	1030	33	65.0	7.7	3.1	36000	5.9	0.0	259	99.28	7.8	0.1	44500	7.7	0.1	36000
	1130	34	67.0	7.6	3.9	36000	6.1	0.0	263	99.27	7.6	0.2	44000	7.7	0.1	36000
	1230	35	69.8	7.6	4.1	36000	7.0	0.0	271	99.25	7.9	0.3	44000	7.8	0.2	36000
	1330	36	72.0	7.7	4.1	36000	7.3	0.0	288	99.20	8	0.2	44500	7.9	0.2	36000
	1430	37	73.5	7.7	4.2	36000	7.8	0	300	99.17	8	0.2	44500	7.9	0.1	36000
	1530	38	74.5	7.9	4	36000	7.2	0	291	99.19	7.9	0.2	44000	8	0.2	36000
	1630	39	75.5	7.8	4.2	36500	6.2	0	303	99.17						
	1730	40	76	7.7	4.3	36000	6.3	0	304	99.16						
TOTALS																
AVERAGE			66.1	7.7	4.8	36000.0	6.1	0.04	263.8	99.27	7.9	0.4	42971	7.9	0.3	36591

Appendix C Summary of Freshwater Test Data

MEMTEC ENGINEERING EVALUATION FRESH WATER TEST DATA

DATE	TIME	TIME (HRS)	RO PRESS (psi)	CMF FILTRATE PRESS	CMF FEED PRESS	CMF DELTA PRESS	FEED TEMP (C)	FEED TEMP (F)	% REDUCTION PER DEG C	TEMP CORR FACTOR	PRODUCT FLOW (GPM)	NORMAL PRODUCT FLOW (GPM)	PRODUCT FLOW (GPD)	NORMAL PRODUCT FLOW (GPD)	BRINE FLOW (GPM)	RECOVERY RATE %	NORMAL REC RATE %
4/05/94	1300	1	229	22.7	29.2	6.5	13.2	55.8	2.56	1.432	3.0	4.3	3960	5670.72	9.0	25	32
	1400	2	227	23.4	29.2	5.8	13.8	56.8	2.58	1.407	3.0	4.2	3960	5571.72	9.0	25	32
	1500	3	228	22.6	29.1	6.5	14.4	58.0	2.60	1.378	3.0	4.1	3960	5456.88	9.0	25	31
	1600	4	222	22.7	29.6	6.9	15.0	59.0	2.61	1.354	3.0	4.1	3960	5361.84	8.0	27	34
	1700	5	222	22.9	29.8	6.9	15.2	59.4	2.62	1.345	3.0	4.0	3960	5326.2	9.0	25	31
4/06/94	830	6	210	21.9	29.3	7.4	13.9	57.0	2.58	1.402	3.1	4.3	4092	5736.984	9.1	25	32
	930	7	212	22.2	29.5	5.8	13.8	56.9	2.58	1.405	3.1	4.4	4092	5749.26	9.1	25	32
	1030	8	209	21.5	29.2	7.7	13.9	57.0	2.58	1.402	3.1	4.3	4092	5736.984	9.1	25	32
	1130	9	209	21.6	29.6	8.0	14.1	57.4	2.59	1.392	3.1	4.3	4092	5696.064	9.0	26	32
	1230	10	206	21.2	29.3	8.1	14.4	58.0	2.60	1.378	3.0	4.1	3960	5456.88	9.0	25	31
	1330	11	211	21.2	29.2	8.0	14.4	58.0	2.60	1.378	3.0	4.1	3960	5456.88	9.0	25	31
	1430	12	206	20.8	29.3	8.5	14.6	58.2	2.60	1.373	3.0	4.1	3960	5437.08	9.0	25	31
	1530	13	209	21.4	30.2	8.8	14.8	58.6	2.61	1.364	3.0	4.1	3960	5401.44	9.0	25	31
	1630	14	205	23.4	29.4	6.0	14.9	58.8	2.61	1.359	3.0	4.1	3960	5381.64	9.0	25	31
	1730	15	203	23.8	29.5	5.7	15.2	59.4	2.63	1.346	3.0	4.0	3960	5330.16	9.0	25	31
	1830	16	207	21.0	29.7	8.7	15.1	59.1	2.61	1.351	3.0	4.1	3960	5349.96	9.0	25	31
	1930	17	207	23.5	29.2	5.7	14.6	58.2	2.60	1.372	3.0	4.1	3960	5433.12	9.0	25	31
4/07/94	800	18	211	20.5	30.0	9.5	13.7	56.7	2.58	1.410	3.1	4.4	4092	5769.72	9.1	25	32
	900	19	211	23.4	29.5	6.1	13.7	56.7	2.58	1.410	3.1	4.4	4092	5769.72	9.1	25	32
	1000	20	211	22.8	29.1	6.3	13.7	56.6	2.57	1.412	3.1	4.4	4092	5777.904	9.1	25	32
	1100	21	214	19.9	30.1	10.2	13.6	56.4	2.57	1.417	3.1	4.4	4092	5798.364	9.1	25	33
	1200	22	213	23.2	29.4	6.2	13.5	56.3	2.57	1.420	3.1	4.4	4092	5810.64	9.1	25	33
	1300	23	212	22.9	29.1	6.2	13.7	56.6	2.57	1.412	3.1	4.4	4092	5777.904	9.1	25	32
	1600	25	220	23.2	29.4	6.2	13.9	57.0	2.58	1.402	3.1	4.3	4092	5736.984	9.1	25	32
	1700	26	213	23.4	29.2	5.8	14.2	57.6	2.59	1.387	3.1	4.3	4092	5675.604	9.1	25	32
	1840	27	199	22.2	28.3	6.1	14.7	58.5	2.60	1.365	3.1	4.2	4092	5585.58	9.0	26	32
4/13/94	1200	29	200	22.3	27.8	5.5	13.7	56.7	2.58	1.410	3.1	4.4	4092	5769.72	9.1	25	32
	1300	30	199				14.2	57.5	2.59	1.39	3	4.2	3960	5504.4	8.1	27	34
	1400	31	200	22.2	28.1	5.9	15.5	59.9	2.63	1.333	3.0	4.0	3960	5278.68	9.0	25	31
	1500	32	198	21.8	27.9	6.1	16.1	60.9	2.65	1.310	3.0	3.9	3960	5187.6	9.0	25	30
	1600	33	193	21.3	27.2	5.9	16.2	61.2	2.65	1.303	3.0	3.9	3960	5159.88	9.0	25	30
	1700	34	192	21.8	27.5	5.7	16.2	61.2	2.65	1.303	3.0	3.9	3960	5159.88	9.0	25	30
4/14/94	1000	35	195	22.2	28.5	6.3	15.0	59.0	2.61	1.354	3.1	4.2	4092	5540.568	9.1	25	32
	1100	36	197	22.3	28.6	6.3	15.3	59.6	2.62	1.340	3.1	4.2	4092	5483.28	9.1	25	31
	1200	37	196	22.1	28.3	6.2	15.6	60.1	2.63	1.328	3.1	4.1	4092	5434.176	9.1	25	31
	1600	38	170	17.8	25.1	7.3	16.2	64.8	2.72	1.226	3.0	3.7	3960	4854.96	8.0	27	31
	1700	39	179	21.5	27.2	5.7	16.5	65.3	2.71	1.214	3.0	3.6	3960	4807.44	8.0	27	31
	1800	40	180				18.9	66.1	3.45	1.264	3.1	3.9	4092	5172.288	8.9	26	31
AVERAGES			206.0	22.1	28.9	6.8	14.8	58.7	2.6		3.0	4.2	4022.5	5489.7	8.9	25.4	31.8

MEMTEC ENGINEERING EVALUATION FRESH WATER TEST DATA

			RAW WATER				PRODUCT WATER				NO REJECT WATER			CMF FILTRATE		
DATE	TIME	ELAPSED TIME (HRS)	TEMP. (F)	pH	TURBIDIT (NTU)	TDS (PPM)	pH	TURBIDIT (NTU)	TDS (PPM)	% REJECTION	pH	TURBIDITY (NTU)	TDS (PPM)	pH	TURBIDITY (NTU)	TDS (PPM)
4/05/94	1300	1	55.8	6.9	16.5	127	5.3	0.0	1.2	99.06	6.9	0	164	7.1	0	137
	1400	2	56.8	7.4	14.8	125	5.7	0.0	0.66	99.31	7.2	0	160	6.9	0	129
	1500	3	58.0	7.0	14.2	122	6.0	0.0	1.02	99.16	7.3	0	161	7.1	0	126
	1600	4	59.0	7.1	14.5	124	5.9	0.0	1.4	98.87	7.3	0	175	7.2	0	127
	1700	5	59.4	7.3	15.2	127	7.7	0.0	0.8	99.37	7.1	0.1	173	7.1	0	128
4/06/94	830	6	57.0	6.8	15.7	121	5.6	0.0	1.2	99.01	7	0	141	7	0	121
	930	7	56.9	6.8	15.7	121	5.5	0.0	1.1	99.09	7.2	0	165	7	0	121
	1030	8	57.0	7.2	15.5	121	5.6	0.0	1.1	99.09		0	156	6.9	0	120
	1130	9	57.4	7.2	14.9	119	6.8	0.0	1.1	99.06	7.2	0	162	7.4	0	120
	1230	10	58.0	7.1	13.4	121	5.9	0.0	1	99.17	7.2	0	158	7.2	0	123
	1330	11	58.0	7.2	14.1	122	5.8	0.0	1	99.18	7.2	0	157	7.1	0	123
	1430	12	58.2	7.3	14.8	120	5.6	0.0	1.4	98.83	7.5	0	156	7.5	0	122
	1530	13	58.6	7.3	15.2	124	5.9	0.0	1.4	98.87	7.4	0	162	7.1	0	125
	1630	14	58.6	7.1	14.2	127	5.8	0.0	1.1	99.13	7.5	0	169	7.4	0	127
	1730	15	59.4	7.5	18.4	132	6.5	0.9	0.86	99.35	7.5	0.9	174	7.3	0.9	126
	1830	16	59.1	7.4	12.8	130	7.4	0.8	0.96	99.26	7.1	0.8	176	7.3	0.6	127
	1930	17	58.2	7.3	30.0	127	8.1	0.9	0.94	99.26	7.5	0.9	193	7.6	0.8	130
4/07/94	800	18	56.7	7.2	16.9	117	6.0	0.0	1.1	99.06	7.4	0	154	7.4	0	117
	900	19	56.7	7.2	14.8	123	6.6	0.0	1.2	99.02	7.6	0	163	7.3	0	122
	1000	20	56.6	7.1	14.9	124	6.5	0.0	1.1	99.11	7.5	0	164	7.2	0	123
	1100	21	56.4	7.3	16.4	123	6.7	0.0	1	99.19	7.5	0	166	7.1	0	123
	1200	22	56.3	7.2	16.5	124	5.9	0.0	1.5	98.79	7.5	0	167	7.3	0	124
	1300	23	56.6	7.2	15.9	125	5.9	0.0	1.1	99.12	7.4	0	164	7.3	0	124
	1600	25	57.0	7.2	15.9	124	5.9	0.0	1.5	98.79	7.4	0	165	7.2	0	125
	1700	26	57.6	7.3	16.5	123	6.0	0.0	1.2	99.02	7.4	0	165	7.2	0	122
	1840	27	58.5	7.7	13.3	127	7.1	0.0	0.92	99.26	7.5	0	166	7.7	0	128
	1940	28		7.1	14.9	129	8.3	0	1.2	99.07	7.4	1.8	167	7.5	1.2	130
4/13/94	1200	29	56.7	7.2	12.5		5.7	0.0								
	1300	30														
	1400	31	59.9	7.2	12.1		6.0	0.0								
	1500	32	60.9	7.2	11.2	154	5.6	0.0	1	99.35	7.7	0	164	7.3	0	151
	1600	33	61.2	7.1	11.3	153	5.7	0.0	1	99.35	7.5	0	182	7.4	0	150
	1700	34	61.2	7.7	10.9	157	5.8	0.0	1	99.36	7.6	0	195	7.2	0	158
4/14/94	1000	35	59.0	7.3	9.7	168	5.6	0.0	1.2	99.29	7.6	0	204	7.5	0	171
	1100	36	59.6	7.2	10.2	167	5.7	0.0	1	99.40	7.8	0	203	7.4	0	170
	1200	37	60.1	7.2	9.9	169	5.7	0.0	1.1	99.35	7.7	0	201	7.4	0	172
	1600	38	64.8	7.4	5.5	170	5.4	0.0	1.4	99.18	7.7	0	197	7.6	0	172
	1700	39	65.3	7.7	6.1	169	5.7	0	1	99.41	8	0	209	7.6	0	177
	1800	40														
AVERAGE			58.5	7.2	14.2	133.0	6.2	0.1	1.1	99.1	7.4	0.1	173.7	7.3	0.1	134.2

Appendix D Safety and Health Assessment Report

AMSTA-RBEQ (385-16a) 11 Apr 94

MEMORANDUM FOR Chief, Water Technology Team, ATTN: AMSTA-RBWE (Luu)

SUBJECT: Safety and Health Assessment of MEMTEC America Corp., MEMCOR Div. 3 GPM, Reverse Osmosis Water Purification Unit (ROWPU), Serial No. 5048, built for USAF STRATCOM

1. Reference: Operations and Maintenance Manual for the MEMCOR ROWPU, Document No. TM40W4-600001-000-2, 25 Mar 94.

2. During government testing on 04-08 Apr 94 of the ROWPU, we evaluated it and its manual against the SOW requirements and noted the following safety and health hazards or shortcomings. This assessment is organized to parallel the Test Plan, CDRL A006.

3. Maintenance Safety - SOW and TP Para 3.2.3.2.4.

a. Battery terminals and ignition coil terminals are not covered with non-conductive covers, which would prevent shorting by tools.

b. There is no capability to lock out the system (prevent starting engine or starting ROWPU section) during maintenance; the Tag Out procedure of the M10 Tool Kit Operating Manual para 3.2 at least warns others against starting/adjusting a system undergoing maintenance.

c. The engine cover plates have burrs and sharp edges in the holes for the quarter-turn latches and the fuel line cutout; these plates also need handles.

d. It is unclear exactly how to depressurize the system.

e. Access for battery maintenance is atrocious; replacing it will be quite difficult. A battery access door is needed badly.

4. Acoustical Noise - Para 3.3.6.1.

a. Exterior noise levels of 85 dBA extend a maximum distance of 11 feet 6 inches from the exterior of the trailer with all doors open. For 85 and 90 dBA noise contours, see Encl 1.

b. Interior noise levels, with the engine/generator covers in place, measured 97 dBA at the operator's control panel and 100 dBA at the fore end. Noise levels were not measured with the engine/generator covers removed nor with the trailer doors closed.

c. The lone hearing protection warning sign should be on the noisy (port, engine) side, not the quiet (starboard, curb) side; it also should be on the outside of the trailer, not on the inside of a door.

d. Sound measurements were performed using a sound meter provided by Mr. Luu. A metal building 55 feet from the trailer may have distorted the true noise levels.

5. Hazardous Materials - Para 3.3.6.2.

a. Although the trailer has no forced ventilation for personnel, carbon monoxide and other exhaust gases should be minimal since the engine exhaust is directed straight up and the rear doors are supposed to always be open during operation. The trailer has four air inlets for natural cross-ventilation; the air inlet within 4 inches of the exhaust outlet should be kept closed to minimize intake of exhaust gases. There was no noticeable accumulation of system chemical vapors.

b. The Material Safety Data Sheet for sodium thiosulfate was not included in the manual; the other hazardous materials used are: sodium hypochlorite, citric acid, and MEMCLEAN (sodium hydroxide).

c. The carboy-to-feedpump lines and connectors for MEMCLEAN and citric acid are identical and could be cross-connected, as are those for sodium hypochlorite and sodium thiosulfate; all four caps are identical. The lines should be labelled on both ends.

d. A handheld eye wash is needed.

e. A 1 inch lip at the front of the chemical storage racks (similar to the one at the back) would improve their horizontal restraint; use non-elastic material impervious to the chemicals. The carboys require vertical restraint also; severe bumps could splash the contents of the non-baffled tanks upward, lifting them over the bungee cords.

f. The goggles (for working with the battery) and face shield, gloves and other "protective clothing" (for the chemicals) are not provided with the system; MEMCOR should specify appropriate National Stock Numbers for these items, enabling the using units to order the appropriate items.

6. Electrical Safety - Para 3.3.6.3.

a. All motors and electrical components need to be rated to withstand a 1,000 psi jet of leaking water. Examples: The windings of the engine cooling air blower motor are open to water splashes; the alternator control box is rated for Indoor service while the open engine exterior access door will constantly expose it to outdoor environments.

b. There are no "Caution - ____ Volts" warnings on or in the control box nor the junction box at the fore end near the dispensing pumps.

c. The MAIN DISCONNECT does not remove engine/generator power to the "complete" system (i.e., to the engine cooling air fan motor); this was done to prevent engine overheating. This motor does not receive power when outside electrical service is used. The MAIN DISCONNECT acts as the required bypassable interlock; it locks the door closed when power is on and removes power when it unlocks the door.

d. The circuit breakers themselves are not labelled and there is no legend listing their function.

e. Live terminal screws are not covered; they are exposed when the interlock is bypassed. However they are recessed and there is little contact area.

f. The TP1 Feed Water Inlet is 3 inches above and to the right of the Feed Pump Power Connection receptacle; upon disconnecting the hose, splashing residual water could short out the terminals in the receptacle (when uncovered). The TP2 Backwash Outlet is 3 inches below and to the right of the Power Connection and is also a source of splashing water. The waterproof capability of the plug itself is doubtful.

g. The location of electrical components needs more thought (e.g., the control box is directly below gallons of water in the RO elements.)

7. Personnel Safety - Para 3.3.6.4.

a. There are no hot parts or surfaces on the interior. The hot engine exhaust flue was well-guarded inside the trailer but was unguarded outside starting at 67 inches above the ground; a perforated metal guard is needed. With the engine exterior access door open (required by the manual), the hot muffler was also exposed; a perforated metal guard is needed. Radiant heat from the muffler and exhaust flue also caused portions of the trailer side wall to be too hot for prolonged contact; these areas could be thermally insulated similarly to that done for interior areas.

b. There is a danger of burning the hand on the hot oil pan, especially when draining the oil from the exterior.

c. There is a fire and burn hazard of spilling oil on a hot muffler; topping off oil may be required during long missions.

d. 5 gallon chemical carboys (approx. 43 lb) are lifted to the 4 ft high rack; there is limited maneuvering room. They will usually not be lifted from the floor but rather carried into the trailer and set into the racks.

e. 5 gallon cans of diesel fuel (approx 45 lb) are poured into the filler 57 inches above ground. This lift will be awkward for females. Any spills would cause a minor fire hazard; the filler is several feet from any heat or spark source.

f. The weight of the loaded hose basket is unknown; weight and any multi-person lift placards need to be applied.

g. The quarter turn engine/generator cover latches protrude about 3/4 inch; they are a strike hazard and are subject to damage; fold-flat latches are preferred.

h. A Universal Flow Monitor at 69 inches above the floor, the RO element mounting brackets at 67 inches and 57 inches and mounting bolts at 56 inches, and the MV18 valve handle are head strike hazards. The mounts need to be rounded or angled. The bolt is covered with a plastic end cap but this does little good; a larger cap (1" diameter minimum) is needed. The valve handle points aft horizontally towards an entering airman; it should be pointed to port (to the engine side).

i. The overhead light is a head strike hazard, especially for tall airmen; it is 73 inches above the floor and directly over the operator. If the airman does not wear a helmet, the broken bulb could cut the head and live electrical filament wires could cause a burn.

j. The low door lintel is 65 inches above the floor and is a head strike hazard, primarily during entry. The bottom edge is covered with a rounded plastic sheath which does little good.

k. The TP1 Feed Water Inlet is 3 inches from the Feed Pump Power Connection; long screws on the connector wire clamp cut the fingers of test personnel when operating the cam levers of the inlet hose. Use shorter screws and move the inlet farther from the connection.

1. The trailer floor is skid-resistant tread plate, however during several operations (e.g., purge, drain) water spilled onto the floor, which has no drains; this water can be removed with available compressed air hose (nozzle meets 29 CFR 1910.242.b). However such water could not be removed if the trailer were pointing downhill. Standing water must be avoided with the use of all these electrical sub-systems! Valves MV-15 and MV-16 need hoses draining to the exterior.

m. The water pressure relief valve is set at 1100 psi and directed away from personnel but not drained out of trailer. The air pressure relief valve is in a seldom occupied area.

8. Mechanical Safety - Para 3.3.6.5.

a. The are no exposed moving parts during operation.

b. The fuel line rubs on the cutout through the engine cover; the cutout needs to be larger and the fuel line needs an abrasion-resistant shroud at that point.

c. There is no grab handle to assist entry; the natural inclination is to grab the handy piping. This could eventually loosen or damage it. Reroute the piping and/or provide a grab handle.

d. To prevent engine overheating, the engine combustion air inlet door, engine cooling air inlet door, and engine exterior access door should have "OPEN BEFORE OPERATING" stencilled on them.

e. Automatic engine shutdown features are not specified.

f. The flame resistance of the engine compartment insulation is not specified; a flame spread classification of 25 or less by ASTM E-84 is desired.

g. Whether the muffler is spark-arresting is not specified; meeting USDA Forest Service STD 5100-1 or SAE J350 is desired.

h. There are no fire extinguishers provided; one rated 10-BC would be adequate.

i. There is no gauge near the fuel filler nor on the internal tank; overfilling would cause a minor fire hazard as the filler is several feet from any heat or spark source.

j. The hose supplying cooling water to the high pressure pump and the air tubing under the compressor are vulnerable to being kicked and damaged.

k. The hydraulic leveling jack has a 2 ton capacity and a short stroke; this may not be adequate for the 6,000 lb system, depending on how much side-to-side leveling is needed. Use of the jack is not addressed in the manual.

9. Grounding, Bonding and Shielding - Para 3.3.8.

a. The ground terminal on the tongue is susceptible to being damaged.

b. Ground points (e.g., in the engine well) seem to be on painted metal; there is minimal intimate terminal-to-frame contact and all current goes only through the screws. Ground connection points on the trailer frame need to be corrosion-protected (e.g., tinned or plated); the frame under the ground terminal on the tongue is already corroding.

c. The grounding rod needs to be in segments; the 8 foot rod provided is unwieldy to drive into ground as it requires climbing onto trailer tongue.

10. Electrical Overload Protection - Para 3.3.10 - Circuit breakers and fuses are adequate.

11. O&M Manual.

a. Warning Summary, page 29 para 2-2, and page 36 - State how to depressurize the system (i.e., turn which valve which way).

b. Warning Summary and page 36 - Include the Tag Out procedure.

c. Page 27, para 2-1.3.2 - "Turn MAIN DISCONNECT to OFF position" should also be the first step when using the engine generator as the power source; this will make the procedure consistent with para 2-1.5.

d. The manual should specify the NSN's of the required goggles, face shield, rubber gloves and other "protective clothing".

e. Summarize (from the MSDS's) the first aid procedures for chemical accidents at the point in the manual where they are first needed.

f. Use of the hydraulic leveling jack is not addressed.

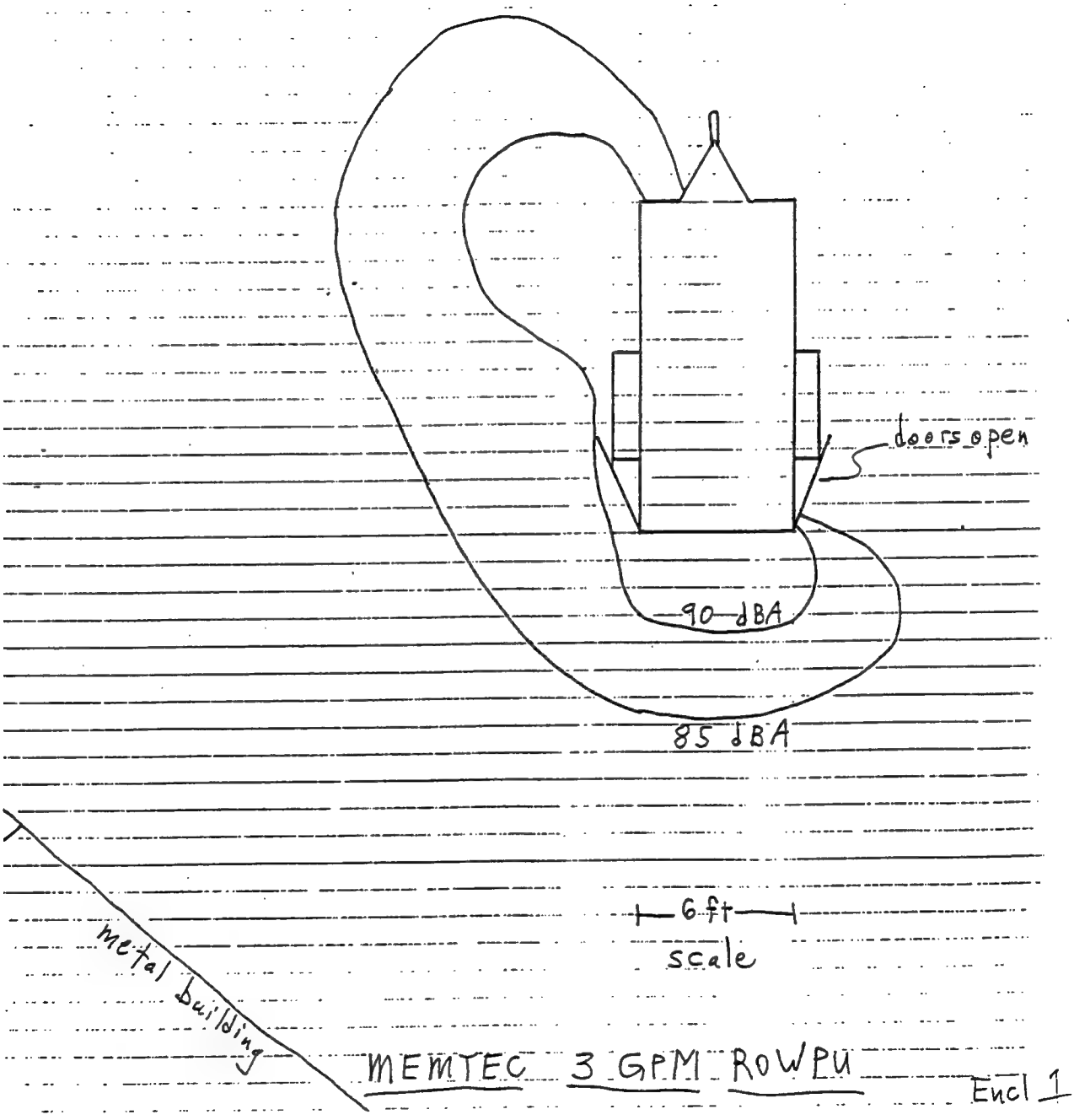
11. Point of contact is Jerry Lyne, 704-2879.

Shawn E. Soltis

Encl

SHAWN E. SOLTIS
Chief
Technical Support Team

usafrowp.sha



MEMTEC 3 GPM ROWPU Encl 1

Appendix E Human Factors Engineering Evaluation Report

DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH LABORATORY
FORT BELVOIR, VIRGINIA 22060-5606

REPLY TO
THE ATTENTION OF

AMSRL-HR-MK

31 March 1994

MEMORANDUM FOR AMSTA-RBWE (Mr. A. Coleman or Mr. T. Bagwell)

SUBJECT: Brief Human Engineering Evaluation of the Air Force Small Reverse Osmosis Water Purification Unit (ROWPU)

1. I discussed the scope and level of effort desired with Mr. Bagwell on 30 March. He requested a brief evaluation. I performed this evaluation on 30 March as the item was undergoing performance testing conducted by AMSTA-RBWE.

2. This ROWPU is being procured by the U.S. Air Force. The serial number on the control panel is 5048.

3. This ROWPU does not conform with MIL-STD-1472 in a number of ways. Additionally, the interior and exterior noise levels far exceed MIL-STD-1474C (Tri-Service) requirements.

4. Design for Human Engineering:

a. I did not see placards that listed cautions or brief operating instructions.

b. I did not find a fuel gauge. The fuel fill port is 63" above the ground. That height and the small (2") opening could cause spillage and possible fire hazard.

c. The engine exhaust port is too close (36") to the air intake port.

d. The engine battery is difficult to access, there is no battery connection diagram, and no high current battery voltage point is booted to prevent short circuit. These aspects cause maintenance to be more difficult and hazardous than need be.

e. The muffler and exhaust stack are not guarded against thermal contact hazard. Contact with very hot surfaces causes immediate tissue trauma.

f. Doors or ports that must be open for operation are not labeled "OPEN BEFORE OPERATING." Failing to open them causes overheating or inadequate ventilation.

g. Labels are a one time cost, over dependance on training is a many times cost. Some of the gauges are not labeled. The labels provided on other gauges read "pd, flow, FM-1, FM-2, FM-3." Most valves are labeled with nomenclature that requires recall, such as "MV-1, PRV-1, NRV-1, AV-1, PL-1" rather than functionally descriptive words. All gauges and valves should be labeled with functionally descriptive labels. For example: RO ELEMENT PRESSURE DIFFERENCE, PRODUCT FLOW, INTAKE WATER FLOW, OUTWASH ON <-----> OFF, etc.

h. Plumbing may burst spraying water; so, electrical safety must be a paramount concern. Most of the equipment in this ROWPU runs on 470 volts, 60 Hz. Therefore, all switches, receptacles, and equipment in ROWPUs must be at least drip-proof. The motor that drives the fresh air blower is not drip-proof. It is an open frame type similar to that used in most home furnaces. That motor is unacceptable.

i. This item was being operated; so, I did not wish to examine electrical equipment in detail. I strongly recommend that all wiring and electrical equipment on this ROWPU be evaluated.

j. The containers for chemical solutions (sodium thiosulfate, chlorate, etc.) are at the rear of the shelter in pretty confined space. Handling the bulky containers is more difficult than it would be if the containers were closer to the entrance. Additionally, though the containers are labeled, the interchangeable caps are not: That could lead to infusing the wrong chemical amounts in product water. Both containers and caps must be labeled. Both should also be color and shape coded to reduce error.

k. I viewed this ROWPU on 29 and 30 March. The plumbing near the doors and control panel leaked from different places on each of those days. Those leaks were probably caused by inadequate strain relief and securement. The plumbing routing near the door can be simplified. The routing should include strain relief loops and better securement.

l. There are small lines at floor level below the air compressor near the flow control panel. Those lines will be damaged by personnel kicking or stepping on them.

m. Controls are not located at eye height (see Figure 1). The engine portion is not labeled properly. Illumination on the control panels is wholly insufficient and poorly distributed. The generator meters are buried under the Reverse Osmosis (RO) vessels and have scales that are hard

to read. The panels should be relocated, properly labeled, and the meter scales should be replaced.

5. Noise:

a. Figure 2. lists internal and external noise levels which vastly exceed MIL-STD-1474C (Tri-Service) requirements. Interior levels of 95 to 96 dB(A) cause a 23% hearing damage risk level. Exterior levels also exceed the commonly required 85 dB(A) at 1 meter level. Hearing damage hazard signs are not posted. Thus, personnel are not warned of the hazard. Hearing loss compensation cost the Army more than $2 billion since 1968. So, controlling the hazard at the source, rather than hoping that warning signs will suffice, is prudent.

b. I did not attempt to understand why noise on this ROWPU is not more confined to the engine space. Experience with other air cooled diesel powered equipment in this horsepower range suggests that noise in this ROWPU can be reduced 10 to 15 dB(A) at reasonable cost. Noise reduction should be pursued.

6. I have not completely evaluated this ROWPU for human engineering. For reasons described above, the human engineering design of this ROWPU is unacceptable. The design deficiencies described can be corrected.

7. Point of contact for this office is Dr. Paul School, DSN 654-2221, CML (703) 704-2221, FAX -2982.

PAUL J. SCHOOL
Ch, HRED Field Element
at Fort Belvoir

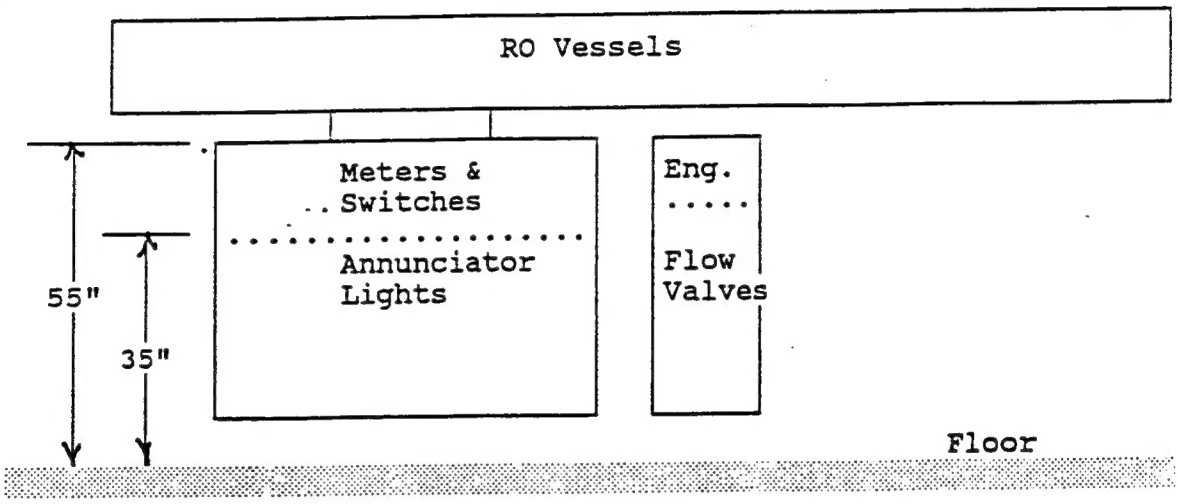


Figure 1. Display heights. This front view sketch is not to scale. The generator gauges are directly above the meters and switches deep under the RO vessels.

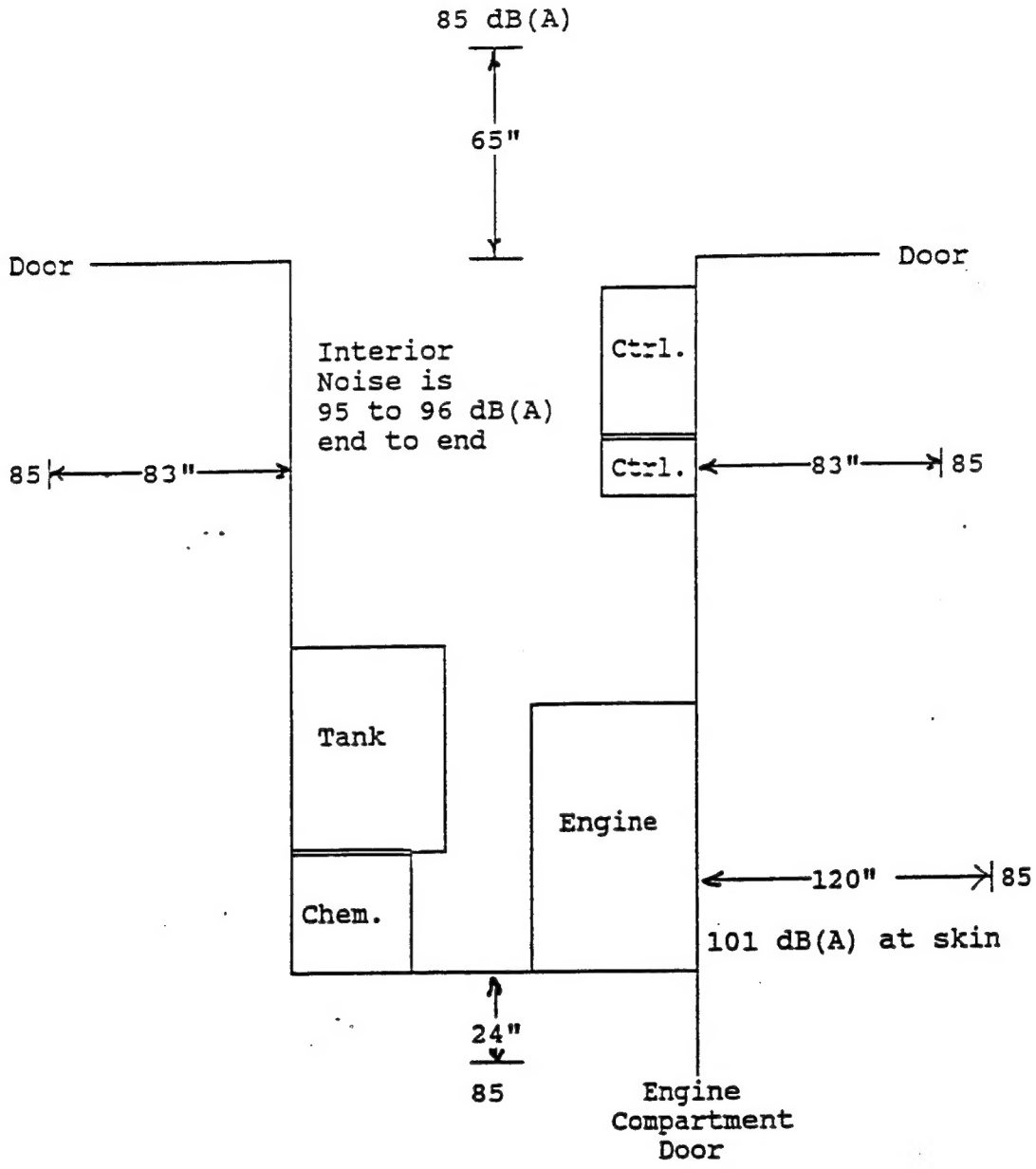


Figure 2. Noise Levels. This top view sketch is not to scale. Doors were open as shown in the sketch. Interior noise level is 95 to 96 dB(A). The exterior 85dB(A) envelope is shown as distances from ROWPU skin where 85 dB(A) was measured. Microphone height was 65" and measurements taken with an ANSI Type I sound meter.

Distribution for TARDEC Technical Report 13618

Commander
US Army Training and Doctrine Command
1 ATTN: ATCD-SL (LTC Mooney)
Fort Monroe, VA 23651-5000

Director
US Army Test and Evaluation Command
1 ATTN: AMXSY-LX (Finkel)
Aberdeen Proving Ground, MD 21005-5071

Commander
US Army Test and Evaluation Command
1 ATTN: AMSTE-TA-G
1 ATTN: AMSTE-TA-S (Jastrab)
Aberdeen Proving Ground, MD 21005-5005

Commander
US Army Operational Evaluation Comman d
1 ATTN: CSTE-ECS (CPT Bonini)
Park Center IV
4501 Ford Avenue
Alexandria, VA 22302-1458

Commander
Naval Facilities Engineering Service Center
1 ATTN: ESC 32 (Kuepper)
560 Laboratory Drive
Port Hueneme, CA 93043-4328

Commander
Marine Corps System Command
1 ATTN: SSE (Alston)
2033 Barnett Ave, Ste 315
Quantico, VA 22134-5010

Commander
US Army Special Operations Command
Deputy Chief of Staff for Force Integrations
1 ATTN: AOFI-CDM (CPT Davis)
Fort Bragg, NC 28307-5200

Commander
US Army Medical Department Center and School
1 ATTN: HSMC-FCM (MAJ Kovak)
Fort Sam Houston, TX 78234-6100

Commander
US Army Center for Health Promotion and
Preventive Medicine (Provisional)
1 ATTN: MCHB-ME-WR (Monahan)
Aberdeen Proving Ground, MD 21010-5422

HQ, Department of the Army
Office of the Surgeon General
1 ATTN: SGPS-PSP-E
5109 Leesburg Pike
Falls Church, VA 22041-3258

Commandant
US Army Quartermaster Center and School
1 ATTN: ATSM-PWD (Bruen)
Fort Lee, VA 23801-5000

Commander
US Army Combined Arms Command
1 ATTN: ATCL-MES-F (Marigliano)
A Ave., Bldg. 10500
Fort Lee, VA 23801-6000

Project Manager Petroleum and Water Logistics
US Army Aviation and Troop Command
1 ATTN: AMCPM-PWL (Butler)
4300 Goodfellow Blvd.
St. Louis, MO 63120-1798

Commander
Test and Experimentation Command
1 ATTN: CSTE-TOP-P (Riley)
Fort Hood, TX 76544-5065

Commander
US Air Force Strategic Command
Mobile C3I Systems Management/J632
1 ATTN: Major John Gibson
Offutt Air Force BAse, NE 68113-6600

Director
Mobility Technology Center-Belvoir
20 ATTN: AMSTA-RBWE
2 ATTN: AMSTA-RBEQ
2 ATTN: AMSTA-HR-MK
2 ATTN: AMSTA-RBXI
Fort Belvoir, VA 22060-5843

12 Defense Tech Info Ctr
Cameron Station
Alexandria, VA 22314